

SPECTROSCOPY OF METAL/TITANIA SYSTEMS(U) TEXAS UNIV AT  
AUSTIN DEPT OF CHEMISTRY Y M SUN ET AL. 15 OCT 85  
TR-39 N00014-83-K-0582

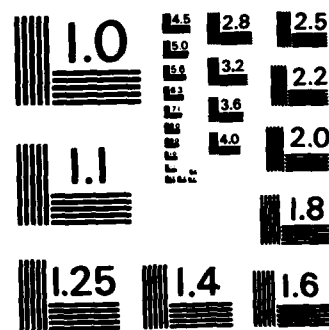
AUSTIN DEPT OF CHEMISTRY Y M SUN ET AL. 15 OCT 85  
TR-39 N00014-83-K-0582

F/G 7/4

NL

END

► [Twitter](#) [Facebook](#)



MICROCOPY RESOLUTION TEST CHART  
NATIONAL BUREAU OF STANDARDS-1963-A

AD-A160 698

OFFICE OF NAVAL RESEARCH

Contract No. N00014-83-K-0582

Task No. NR 056-578

TECHNICAL REPORT NO. 39

Spectroscopy of Metal/Titania Systems

by

Y.-M. Sun, D. N. Belton and J. M. White

Prepared for publication

in

ACS (Preprints) Div. Petrol. Chem. 29(1984)749

Department of Chemistry

The University of Texas at Austin

Austin, Texas 78712

DTIC  
ELECTE  
OCT 23 1985  
S D  
B

Reproduction in whole or in part is permitted for any purpose of the  
United States Government.

This document has been approved for public release and sale; its  
distribution is unlimited.

85 10 23 030

DTIC FILE COPY

| REPORT DOCUMENTATION PAGE  |                       | READ INSTRUCTIONS<br>BEFORE COMPLETING FORM  |
|--|-----------------------|--|
| 1. REPORT NUMBER   | 2. GOVT ACCESSION NO. | 3. RECIPIENT'S CATALOG NUMBER  |
|  | AD-A160698            |  |
| 4. TITLE (and Subtitle)<br>Spectroscopy of Metal/Titania Systems   |                       | 5. TYPE OF REPORT & PERIOD COVERED<br>Technical Report 39<br>January 1 - December 31, 1985 |
|  |                       | 6. PERFORMING ORG. REPORT NUMBER   |
| 7. AUTHOR(s)<br>Y.-M. Sun, D. N. Belton and J. M. White  |                       | 8. CONTRACT OR GRANT NUMBER(s)<br>N00014-83-K-0582   |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br>J. M. White, Department of Chemistry<br>University of Texas<br>Austin, TX 78712   |                       | 10. PROGRAM ELEMENT, PROJECT, TASK<br>AREA & WORK UNIT NUMBERS<br>Project No. NR-056-578   |
| 11. CONTROLLING OFFICE NAME AND ADDRESS<br>Department of the Navy<br>Office of Naval Research<br>Arlington, VA 22217   |                       | 12. REPORT DATE<br>October 15, 1985  |
|  |                       | 13. NUMBER OF PAGES<br>6   |
| 14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)  |                       | 15. SECURITY CLASS. (of this report)   |
|  |                       | 15a. DECLASSIFICATION/DOWNGRADING<br>SCHEDULE  |
| 16. DISTRIBUTION STATEMENT (of this Report)<br><br>Approved for public release; distribution unlimited.  |                       |  |
| 17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)   |                       |  |
| 18. SUPPLEMENTARY NOTES<br><br>Preprints: ACS(Preprints) Div. Petrol. Chem. 29(1984)749  |                       |  |
| 19. KEY WORDS (Continue on reverse side if necessary and identify by block number)   |                       |  |
| 20. ABSTRACT (Continue on reverse side if necessary and identify by block number)<br>Thin film models of catalysts known to show strong metal support interactions were investigated. These consist of vapor-deposited Pt or Rh on TiO <sub>2</sub> films prepared in ultrahigh vacuum by oxidation of Ti(000±). TDS, AES and static SIMS were used to characterize the surfaces before and after thermal treatment in vacuum and with or without chemisorbed CO. The results indicate that heating in vacuum to near 750K leads to migration of a reduced form of titania to the metal film surface, accompanied by suppression of CO and hydrogen chemisorption. In 1 to 2 ML metal films with no surface titania species, no significant suppression of hydrogen chemisorption is seen, indicating that surface segregation alone is not responsible for the changes in hydrogen chemisorption extent and energetics. |                       |  |

DD FORM 1473  
1 JAN 73EDITION OF 1 NOV 65 IS OBSOLETE  
S/N 0102-014-6601

Y.-M. Sun, D. N. Belton and J. M. White

Department of Chemistry  
The University of Texas at Austin  
Austin, Texas 78712

We have investigated thin film models of catalysts which are known to show strong metal-support interactions. These models consist of vapor-deposited platinum or rhodium on titanium dioxide films prepared in ultrahigh vacuum by oxidation of Ti(0001). Thermal desorption spectroscopy, Auger electron spectroscopy and static secondary ion mass spectrometry have been used to characterize the surfaces of these films before and after thermal treatment in vacuum and with or without chemisorbed carbon monoxide. The results indicate that heating in vacuum to temperatures near 750 K leads to the migration of a reduced form of titanium to the surface of the metal films. This migration is accompanied by significant suppression of carbon monoxide and hydrogen chemisorption just as is found in powdered oxide-supported transition metal catalysts. Sputtering removes the segregated titanium-oxygen species, and the chemisorption of carbon monoxide is nearly completely recovered. In thin films of metal that are one to two monolayers thick with no surface titanium species, there is no significant suppression of hydrogen chemisorption, indicating that surface segregation is, by itself, not fully responsible for the observed changes in the extent and energetics of hydrogen chemisorption on these surfaces. Clearly, both site-blocking and electronic (bonding) effects play a role in the observed strong metal-support interaction effects.

Recently there has been a great deal of interest in the systems which exhibit strong metal-support interactions (SMSI) (1-12). This activity was stimulated by the work of Tauster et al. (1,2) reported in 1978 which showed that Group VIII transition metals supported on reducible metal oxides were subject to large-scale suppression of chemisorption of hydrogen when the oxides were reduced at high temperatures. Since then there have been a number of papers and conferences on this subject. Proposed explanations include the migration or segregation of oxide species over the transition metal

particles and electronic effects including Pt-titanium bonding and/or charge transfer from the support to the metal.

We have undertaken a series of experiments involving thin film models of such powdered transition metal catalysts (13,14). In this paper we present a brief review of the results we have obtained to date involving platinum and rhodium deposited on thin films of titanium, the latter prepared by oxidation of a titanium single crystal. These systems are prepared and characterized under well-controlled conditions. We have used thermal desorption spectroscopy (TDS), Auger electron spectroscopy (AES) and static secondary ion mass spectrometry (SSIMS). Our results illustrate the power of SSIMS in understanding the processes that take place during thermal treatment of these thin films. Thermal desorption spectroscopy is used to characterize the adsorption and desorption of small molecules, in particular, carbon monoxide. AES confirms the SSIMS results and was used to verify the surface cleanliness of the films as they were prepared.

### Experimental

The experiments were conducted in an ultrahigh vacuum chamber equipped with a cylindrical mirror electron energy analyzer, a quadrupole mass spectrometer with a Bessel box energy filter for analysis of secondary ions, and an Ar<sup>+</sup> gun. A Ti(0001) single crystal was mounted on a liquid nitrogen cooled and resistively heated manipulator assembly. The surfaces were cleaned by argon ion bombardment and annealing cycles. The transition metals were deposited using thermal evaporation sources. During the experiments, pressures were routinely  $3 \times 10^{-11}$  torr.

The titanium-based thin film catalyst models were constructed by first oxidizing the titanium surface in  $5 \times 10^{-5}$  torr of O<sub>2</sub> for approximately 30 minutes at 775 K. This produced an AES line shape consistent with fully oxidized TiO<sub>2</sub>. The metal was then vapor deposited onto the oxide support with the latter held at 130 K. The thickness of the metal overlayer and its cleanliness were verified by AES. After various annealing and adsorption procedures, these thin films were further characterized using SSIMS, AES and TDS. For comparison, some work was done with Pt on Al<sub>2</sub>O<sub>3</sub>. In this case a Mo foil covered with Al<sub>2</sub>O<sub>3</sub> replaced the Ti(0001) substrate.

### Results

Figure 1 shows AES data for the oxidized titanium surface before and after deposition of 30 Å of platinum with the substrate held at 130 K. The platinum thickness was calculated from the attenuation of the oxygen AES signal assuming layered growth of the metal. From the spectra it is clear that the platinum was sufficient to completely attenuate the underlying features of the titanium oxide. The spectra of the oxide surface prior to metal deposition is characteristic of fully oxidized titanium. In the region just below 435 eV the line shape is significantly different for different oxides of titanium (15).

Figure 2 shows the results of heating a model system consisting of a 30 Å platinum film on oxidized titanium. A linear temperature ramp was applied until the foil reached 760 K, after which the temp-

erature was held constant for approximately 5 minutes and then the sample was cooled. During these temperature changes the  $Ti^{+}$  SSIMS signal was followed. Near 615 K the  $Ti^{+}$  signal begins to rise sharply. This signal continues to rise during the period when the temperature is held constant at 760 K. Upon cooling there was no tendency for the signal to decrease.

A similar sample was heated as above and then subjected to argon ion sputtering, as indicated in Fig. 3. An argon ion current of 0.3 mA was utilized and the  $Ti^{+}$  signal was followed as a function of sputtering time. This figure indicates a sharp decay of the  $Ti^{+}$  signal followed by a relatively wide region where very little signal is noted. Deeper into the sample the  $Ti^{+}$  signal rises steadily, maximizes at about 600 seconds and then decays.

On a third sample, thermal desorption of carbon monoxide was carried out before and after annealing to 760 K and after sputtering into the region where the  $Ti^{+}$  was a minimum (i.e., about 180 seconds in Fig. 3). The TDS results are summarized in Table 1. The last column gives the integrated peak desorption area for carbon monoxide.

Table 1. CO Thermal Desorption Spectra.

| Substrate   | Anneal Temp (K) | Desorption Peak (T) | Total Peak Area |
|-------------|-----------------|---------------------|-----------------|
| $TiO_2$     | 525             | 400                 | 1.00            |
| $TiO_2$     | 775             | 355                 | 0.33            |
| $TiO_2$ (S) | 525             | 400                 | 0.95            |
| $Al_2O_3$   | 525             | 400                 | 1.00            |
| $Al_2O_3$   | 775             | 400                 | 0.98            |

(S)=sputtered (see text)

Two CO desorption peaks (400 and 510 K) were observed on the as-deposited Pt layer. However, for a sample annealed to 525 K the intensity of the high temperature CO peak was one third its original value. Thus, after annealing to 525 K, the desorption profile consisted of a large peak at 400 K with a shoulder at 510 K. For this reason we report the peak temperature for the low temperature peak only; however, the 510 K shoulder is included in the reported peak area. Comparison of our data to results from other surfaces shows reasonable agreement. Polycrystalline Pt(415 K, 507 K) (16), Pt(110) (430 K, 530 K) (17) and Pt(111) (420 K, 530 K) (18) all have two desorption peaks in the 400-550 K range. For both titania- and alumina-supported Pt, the areas are normalized to the desorption area after annealing the 30 Å overlayer to 525 K and adsorbing CO to saturation at 130 K. For titania annealed to 775 K the peak desorption temperature is decreased by about 45 K, and the total area is decreased by a factor of 3. After sputtering to the minimum and reannealing to 525 K, the peak temperature returns to 400 K and the total peak area increases to approximately its value before the

annealing experiment was carried out. Similar experiments were done with Pt on alumina. As indicated in Table 1, annealing to 760 K does not change either the desorption temperature or the area under the carbon monoxide desorption peak.

Similar SSIMS and TDS results were obtained for rhodium on titania and for hydrogen chemisorption on both substrates. In a blank experiment involving no metal overlayer, temperature programming while following the  $Ti^{+}$  and  $TiO^{+}$  SIMS signals (Fig. 4) shows that the titania thin film does not begin to change until the temperature reaches about 760 K, well beyond the 615 K where  $Ti^{+}$  was first noted to increase on the systems with thin metal overlayers.

To explore the possibility of electronic interaction between the reduced titanium oxide and Pt, 1 ML of Pt was deposited on both fully oxidized and partially reduced  $TiO_2$ . The reduced sample was prepared by  $Ar^{+}$  sputtering of the  $TiO_2$  substrate prior to metal deposition, introducing reduced Ti centers at the Pt-Ti interface.  $H_2$  TDS was used as the highest  $H_2$  desorption temperature (370 K) occurs below the temperature regime of encapsulation. For the reduced sample there was a 70% decrease in  $H_2$  chemisorption and a 33 K shift to lower temperatures when the unannealed sample (first  $H_2$  TDS) was compared to the sample annealed at 370 K (second  $H_2$  TDS). No change in the AES was observed after either the first or second TDS, showing that the Pt overlayer does not island or encapsulate. We take these low Pt coverage experiments to indicate an electronic interaction (preferably bond formation, which does not require significant charge transfer) between Pt and reduced Ti species that is activated at about 370 K.

For the fully oxidized sample the results were somewhat different. After annealing at 370 K there was 25% less  $H_2$  adsorption, and the peak split into two peaks, one shifted higher and one lower, each by about 30 K. There were also small changes in the AES Pt/Ti ratio after the first TDS. Since  $TiO_2$  migrates at lower temperatures for reduced titania, as compared to fully oxidized, we do not favor  $TiO_2$  migration as the explanation. Rather, we suggest that the changes observed after the 370 K anneal of the oxidized sample are due to small changes in the morphology of the Pt overlayer. These alter the number and kind of exposed Pt sites.

## Discussion

From the SIMS, AES and TDS data the following picture emerges. Oxidation of titanium in situ leads to the formation of a film of fully oxidized titania that is thick enough to completely attenuate metal and suboxide contribution to the AES spectra. Heating these overlayers, which are judged to be more than 60 Å thick, results in no detectable changes by SIMS or by AES (not shown) until the temperature exceeds 760 K. Since thermal effects are observed at significantly lower temperature when metal overlayers are present, we conclude that those observations are not due to degradation of the oxide layer via diffusion of oxygen into the bulk metal.

The AES signals observed after deposition of platinum (Fig. 1) indicate that platinum goes down reasonably uniformly under our conditions. This result is confirmed by a more detailed analysis of the attenuation of the oxygen and titanium signals as a function

of platinum dosing time. From these results (not shown) we conclude that platinum deposition occurs in a very nearly layer-by-layer fashion at 130 K. Annealing these films to 525 K does nothing to the  $Ti^{2+}$  SWS signal, but at around 600 K  $Ti^{2+}$  signals begin to appear in the SWS spectra. These rise sharply to a fairly steady value which increases slowly with time. This is a thermally irreversible change since, upon cooling, (Fig. 2) the  $Ti^{2+}$  signal does not return to a low value. The species formed is largely segregated to the surface as indicated by this sputtering profile of Fig. 3. Sputtering removes this overlayer and leads to metallic platinum. After sputtering through the platinum the oxide region is again reached. After 600 seconds the metal layer is removed, and the  $Ti^{2+}$  signal begins to drop. This final drop is the result of a decreasing cross-section for ion desorption which accompanies the preferential removal of oxygen.

The observed thermal desorption results are entirely consistent with the picture that emerges from Figs. 2 and 3. Annealing to 525 K (Table 1) gives a thermal desorption peak for carbon monoxide like that observed from bulk platinum films. Annealing to 775 K lowers the desorption peak temperature and, more importantly, attenuates sharply the amount of carbon monoxide that will adsorb. Sputtering to the minimum of the  $Ti^{2+}$  signal followed by an anneal to 525 K and adsorption gives a result that is very much like that observed prior to the high-temperature anneal. From these and other more detailed results involving Auger lineshape studies, we conclude that the species that migrates to the surface of the platinum is probably  $TiO$ .

For similar samples on alumina, these effects are not observed, as indicated in Table 1. No migration of aluminum or oxygen species is observed in AES, and the capacity of the film to adsorb carbon monoxide is not altered by changing the annealing temperature from 525 to 760 K.

All of these results are consistent with the notion that surface migration of titanium oxide species is an important factor that contributes to the suppression of carbon monoxide chemisorption. The N<sub>2</sub> chemisorption experiments on 1-2 ML of Pt, where no migration is observed, strongly indicate that electronic (bonding) interactions are also occurring. Thus, for the titania system, both electronic interactions and surface site blocking due to titanium oxide species must be considered in interpreting SWSI effects.

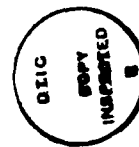
#### Acknowledgments

This work was supported in part by the Office of Naval Research.

#### Literature Cited

1. Tauster, S. J.; Fung, S. C.; Garten, R. L. *J. Am. Chem. Soc.* 1978, 100, 170.
2. Tauster, S. J.; Fung, S. C. *J. Catal.* 1978, 55, 29.
3. Imelik, B. et al.; eds. "Metal-Support and Metal Additive Effects in Catalysis"; Elsevier: Amsterdam, 1982, and references cited therein.

4. Huizinga, T. "Metal Support Interactions in Pt and Rh Al<sub>2</sub>O<sub>3</sub> and TiO<sub>2</sub> Catalysts, Ph.D. Thesis, Eindhoven University of Technology, 1983.
5. Jiang, X.-J.; Bayden, T. F.; Dumesic, J. A. *J. Catal.* 1983, 83, 68.
6. Resasco, D. E.; Maller, G. L. *J. Catal.* 1983, 82, 279.
7. Vanice, M. A.; Tse, C. C. *J. Catal.* 198, 82, 213.
8. Short, D. R.; Mansour, A. N.; Cook, J. W. Jr.; Sayers, D. E.; Katzen, J. R. *J. Catal.* 1982, 82, 299.
9. Fang, S.-M.; White, J. H. *J. Catal.* 1983, 83, 1.
10. Tanaka, K.; White, J. H. *J. Catal.* 1983, 79, 81.
11. Baker, R. T. K. *J. Catal.* 1980, 63, 323.
12. Fung, S. C. *J. Catal.* 1982, 76, 225.
13. Belton, D. N.; Sun, Y.-M.; White, J. H. *J. Am. Chem. Soc.* (in press).
14. Belton, D. N.; Sun, Y.-M.; White, J. H. *J. Phys. Chem.* (in press).
15. Davis, G. D.; Natan, M.; Anderson, K. A. *Appl. Surface Sci.* 1983, 15, 321.
16. Thruha, K. A.; White, J. H., unpublished results.
17. McCabe, R. W.; Schmidt, L. D. *Surface Sci.* 1976, 60, 85.
18. Collins, D. M.; Spicer, W. E. *Surface Sci.* 1977, 69, 55.



|                    |                                     |
|--------------------|-------------------------------------|
| Accession For      |                                     |
| NTIS GRA&I         | <input checked="" type="checkbox"/> |
| DTIC TAB           | <input type="checkbox"/>            |
| Unannounced        | <input type="checkbox"/>            |
| Justification      |                                     |
| By                 |                                     |
| Distribution/      |                                     |
| Availability Codes |                                     |
| Dist               | Avail and/or Special                |
| A-1                |                                     |

## FIGURE CAPTIONS

Figure 1 AES spectra of oxidized Ti(0001) (top) and oxidized Ti with 30 Å Pt (bottom).

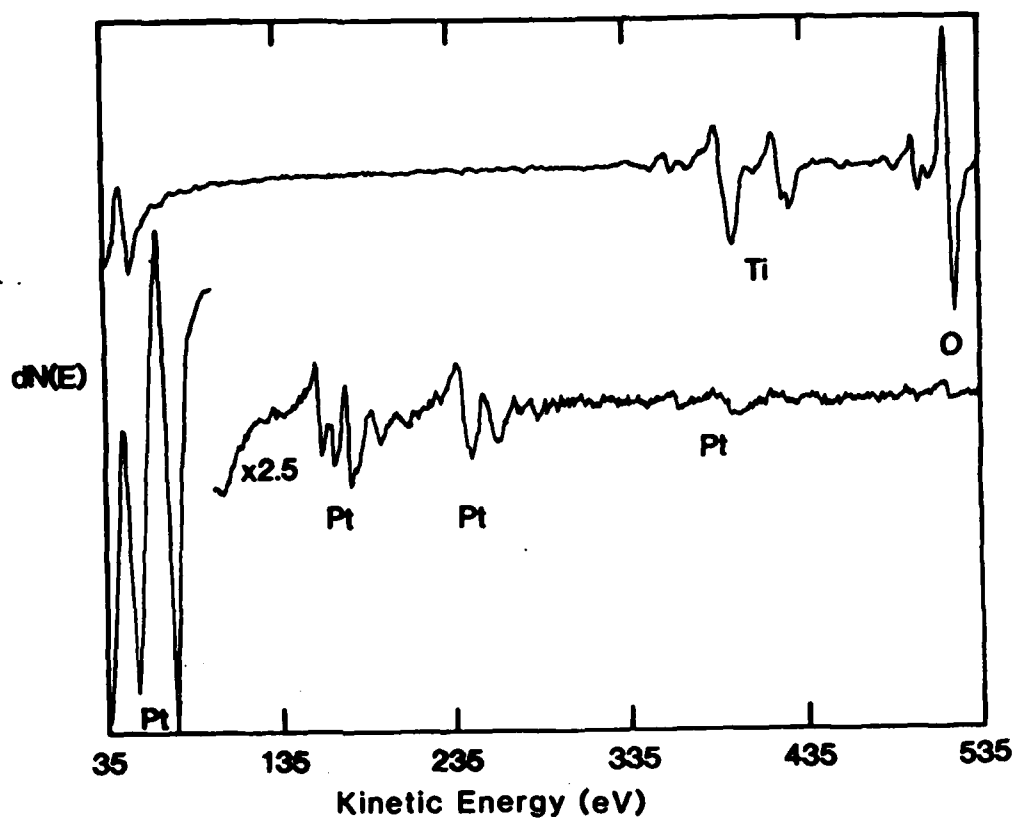
Figure 2 TPSSIMS for 30 Å Pt on oxidized Ti(0001).

Figure 3 Ti<sup>+</sup> SIMS depth profile of 30 Å Pt on oxidized Ti(0001) annealed to 760 K.

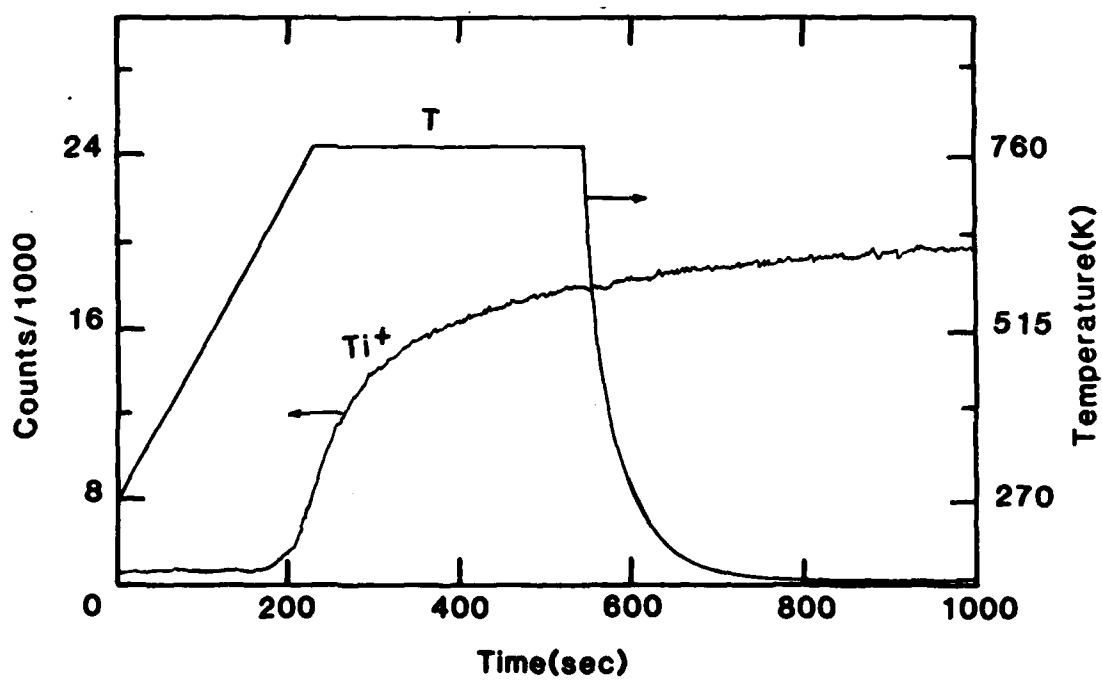
Figure 4 TPSSIMS of the oxidized Ti(0001) substrate without a metal overlayer.

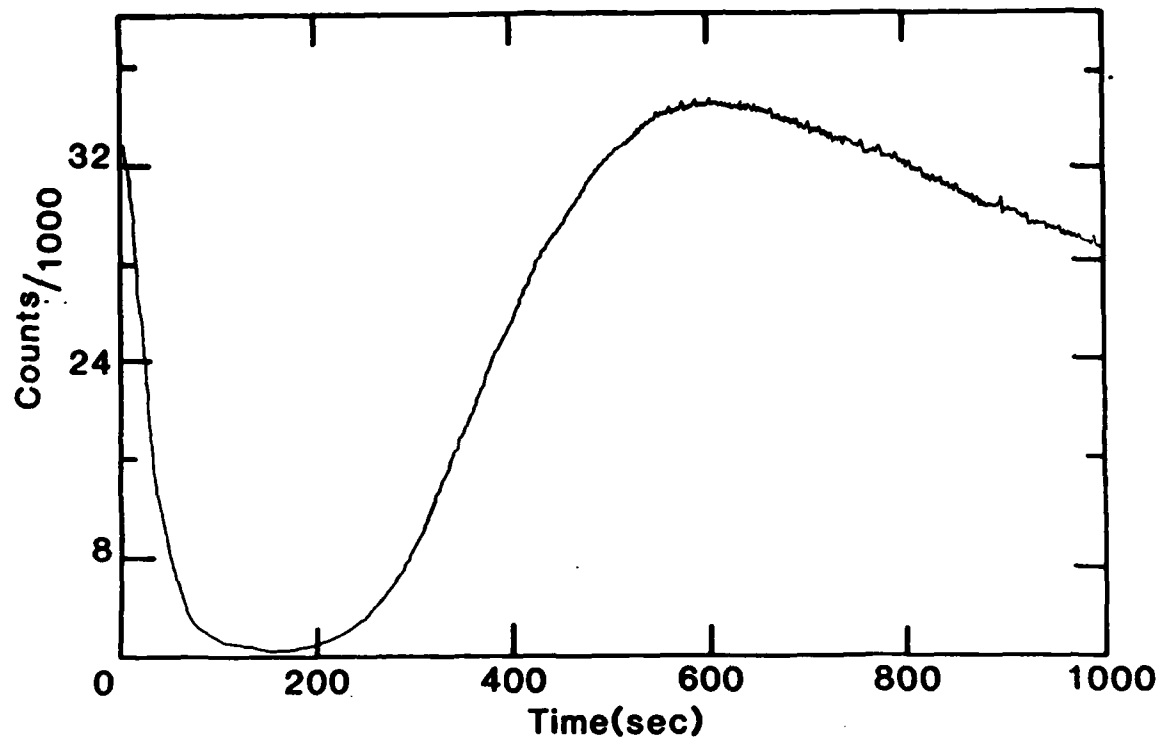
Figure 1. AES spectra of oxidized Ti(0001) (top) and oxidized Ti with 30 Å Pt (bottom).  
 Figure 2. TPSSIMS for 30 Å Pt on oxidized Ti(0001).  
 Figure 3. Ti<sup>+</sup> SIMS depth profile of 30 Å Pt on oxidized Ti(0001) annealed to 760 K.  
 Figure 4. TPSSIMS of the oxidized Ti(0001) substrate without a metal overlayer.



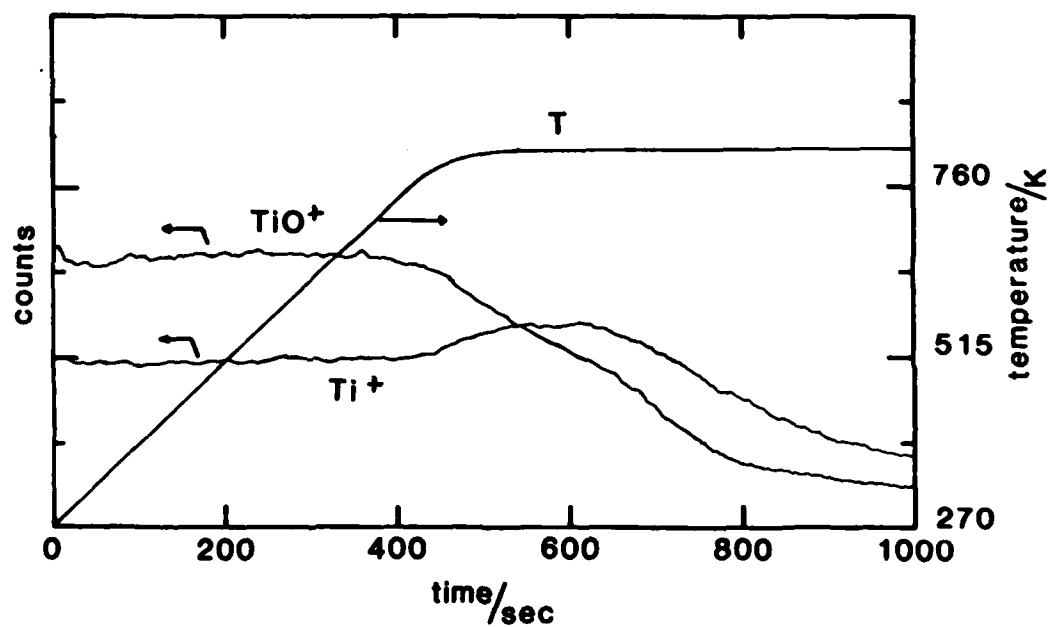


Sun, Belton & White  
Figure 1





Sun, Belton & M  
Figure 3



## ABSTRACTS DISTRIBUTION LIST, 056/625/629

Dr. F. Carter  
Code 6132  
Naval Research Laboratory  
Washington, D.C. 20375

Dr. Richard Colton  
Code 6112  
Naval Research Laboratory  
Washington, D.C. 20375

Dr. Dan Pierce  
National Bureau of Standards  
Optical Physics Division  
Washington, D.C. 20234

Dr. R. Stanley Williams  
Department of Chemistry  
University of California  
Los Angeles, California 90024

Dr. R. P. Messner  
Materials Characterization Lab.  
General Electric Company  
Schenectady, New York 12217

Dr. Robert Gomer  
Department of Chemistry  
James Franck Institute  
5640 Ellis Avenue  
Chicago, Illinois 60637

Dr. Ronald Lee  
R301  
Naval Surface Weapons Center  
White Oak  
Silver Spring, Maryland 20910

Dr. Paul Schoen  
Code 5570  
Naval Research Laboratory  
Washington, D.C. 20375

Dr. John T. Yates  
Department of Chemistry  
University of Pittsburgh  
Pittsburgh, Pennsylvania 15260

Dr. Richard Greene  
Code 5230  
Naval Research Laboratory  
Washington, D.C. 20375

Dr. L. Kesmodel  
Department of Physics  
Indiana University  
Bloomington, Indiana 47403

Dr. K. C. Janda  
California Institute of Technology  
Division of Chemistry and Chemical  
Engineering  
Pasadena, California 91125

Dr. E. A. Irene  
Department of Chemistry  
University of North Carolina  
Chapel Hill, North Carolina 27514

Dr. Adam Heller  
Bell Laboratories  
Murray Hill, New Jersey 07974

Dr. Martin Fleischmann  
Department of Chemistry  
Southampton University  
Southampton SO9 5NH  
Hampshire, England

Dr. John W. Wilkins  
Cornell University  
Laboratory of Atomic and  
Solid State Physics  
Ithaca, New York 14853

Dr. Richard Smardzewski  
Code 6130  
Naval Research Laboratory  
Washington, D.C. 20375

Dr. H. Tachikawa  
Chemistry Department  
Jackson State University  
Jackson, Mississippi 39217

## ABSTRACTS DISTRIBUTION LIST, 056/625/629

Dr. G. A. Somorjai  
Department of Chemistry  
University of California  
Berkeley, California 94720

Dr. J. Munday  
Naval Research Laboratory  
Surface Chemistry Division (6170)  
455 Overlook Avenue, S.W.  
Washington, D.C. 20375

Dr. J. B. Hudson  
Materials Division  
Rensselaer Polytechnic Institute  
Troy, New York 12181

Dr. Theodore E. Medley  
Surface Chemistry Section  
Department of Commerce  
National Bureau of Standards  
Washington, D.C. 20234

Dr. J. E. Demuth  
IBM Corporation  
Thomas J. Watson Research Center  
P.O. Box 218  
Yorktown Heights, New York 10598

Dr. M. G. Lagally  
Department of Metallurgical  
and Mining Engineering  
University of Wisconsin  
Madison, Wisconsin 53706

Dr. R. P. Van Dyne  
Chemistry Department  
Northwestern University  
Evanston, Illinois 60637

Dr. J. M. White  
Department of Chemistry  
University of Texas  
Austin, Texas 78712

Dr. D. E. Harrison  
Department of Physics  
Naval Postgraduate School  
Monterey, California 93940

Dr. W. Kohn  
Department of Physics  
University of California, San Diego  
La Jolla, California 92037

Dr. R. L. Park  
Director, Center of Materials  
Research  
University of Maryland  
College Park, Maryland 20742

Dr. W. T. Perla  
Electrical Engineering Department  
University of Minnesota  
Minneapolis, Minnesota 55455

Dr. Keith H. Johnson  
Department of Metallurgy and  
Materials Science  
Massachusetts Institute of Technology  
Cambridge, Massachusetts 02139

Dr. S. Sibener  
Department of Chemistry  
James Franck Institute  
5640 Ellis Avenue  
Chicago, Illinois 60637

Dr. Arnold Green  
Quantum Surface Dynamics Branch  
Code 3817  
Naval Weapons Center  
China Lake, California 93555

Dr. A. Wold  
Department of Chemistry  
Brown University  
Providence, Rhode Island 02912

Dr. S. L. Bernasconi  
Department of Chemistry  
Princeton University  
Princeton, New Jersey 08544

Dr. P. Lund  
Department of Chemistry  
Howard University  
Washington, D.C. 20059

ABSTRACTS DISTRIBUTION LIST, 056/625/629

Dr. J. E. Jensen  
Hughes Research Laboratory  
3011 Malibu Canyon Road  
Malibu, California 90265

Dr. J. H. Weaver  
Department of Chemical Engineering  
and Materials Science  
University of Minnesota  
Minneapolis, Minnesota 55455

Dr. W. Goddard  
Division of Chemistry  
California Institute of Technology  
Pasadena, California 91125

Dr. A. Reisman  
Microelectronics Center of North Carolina  
Research Triangle Park, North Carolina  
27709

Dr. M. Grunze  
Laboratory for Surface Science and  
Technology  
University of Maine  
Orono, Maine 04469

Dr. J. Butler  
Naval Research Laboratory  
Code 6115  
Washington D.C. 20375

Dr. L. Interante  
Chemistry Department  
Rensselaer Polytechnic Institute  
Troy, New York 12181

Dr. Irvin Heard  
Chemistry and Physics Department  
Lincoln University  
Lincoln University, Pennsylvania 19352

Dr. K.J. Klaubunde  
Department of Chemistry  
Kansas State University  
Manhattan, Kansas 66506

Dr. W. Knauer  
Hughes Research Laboratory  
3011 Malibu Canyon Road  
Malibu, California 90265

Dr. C. B. Harris  
Department of Chemistry  
University of California  
Berkeley, California 94720

Dr. F. Kutzler  
Department of Chemistry  
Box 5055  
Cookeville, Tennessee 38501

Dr. D. DiLella  
Chemistry Department  
George Washington University  
Washington D.C. 20032

Dr. R. Reeves  
Chemistry Department  
Rensselaer Polytechnic Institute  
Troy, New York 12181

ABSTRACTS DISTRIBUTION LIST, 056/625/629

Dr. R. G. Wallis  
Department of Physics  
University of California  
Irvine, California 92664

Dr. D. Ramaker  
Chemistry Department  
George Washington University  
Washington, D.C. 20052

Dr. J. C. Hemminger  
Chemistry Department  
University of California  
Irvine, California 92717

Dr. T. F. George  
Chemistry Department  
University of Rochester  
Rochester, New York 14627

Dr. G. Rudloff  
IBM  
Thomas J. Watson Research Center  
P.O. Box 218  
Yorktown Heights, New York 10598

Dr. Horfa Metfu  
Chemistry Department  
University of California  
Santa Barbara, California 93106

Dr. W. Goddard  
Division of Chemistry  
California Institute of Technology  
Pasadena, California 91125

Dr. J. T. Keiser  
Department of Chemistry  
University of Richmond  
Richmond, Virginia 23173

Dr. R. W. Plummer  
Department of Physics  
University of Pennsylvania  
Philadelphia, Pennsylvania 19104

Dr. E. Yeager  
Department of Chemistry  
Case Western Reserve University  
Cleveland, Ohio 44106

Dr. N. Minograd  
Department of Chemistry  
Pennsylvania State University  
University Park, Pennsylvania 16802

Dr. Roald Hoffmann  
Department of Chemistry  
Cornell University  
Ithaca, New York 14853

Dr. A. Steckl  
Department of Electrical and  
Systems Engineering  
Rensselaer Polytechnic Institute  
Troy, New York 12181

Dr. G. H. Morrison  
Department of Chemistry  
Cornell University  
Ithaca, New York 14853

Dr. P. Hansma  
Physics Department  
University of California  
Santa Barbara, California 93106

Dr. J. Baldeschwieler  
California Institute of Technology  
Division of Chemistry  
Pasadena, California 91125

TECHNICAL REPORT DISTRIBUTION LIST, GEN

|  | <u>No.<br/>Copies</u> | <u>No.<br/>Copies</u>  |
|--|-----------------------|--|
| Office of Naval Research<br>Attn: Code 413<br>800 M. Quincy Street<br>Arlington, Virginia 22217                              | 2                     | Dr. David Young<br>Code 334<br>NORDA<br>NSTL, Mississippi 39529  |
| Dr. Bernard Douda<br>Naval Weapons Support Center<br>Code 5042<br>Crane, Indiana 47522                                       | 1                     | Naval Weapons Center<br>Attn: Dr. Ron Atkins<br>Chemistry Division<br>China Lake, California 93555             |
| Commander, Naval Air Systems<br>Command<br>Attn: Code 310C (H. Rosenwasser)<br>Washington, D.C. 20360                        | 1                     | Scientific Advisor<br>Commandant of the Marine Corps<br>Code RD-1<br>Washington, D.C. 20380                    |
| Naval Civil Engineering Laboratory<br>Attn: Dr. R. W. Drisko<br>Port Hueneme, California 93401                               | 1                     | U.S. Army Research Office<br>Attn: CRD-AA-IP<br>P.O. Box 12211<br>Research Triangle Park, NC 27709             |
| Defense Technical Information Center<br>Building 5, Cameron Station<br>Alexandria, Virginia 22314                            | 12                    | Mr. John Boyle<br>Materials Branch<br>Naval Ship Engineering Center<br>Philadelphia, Pennsylvania 19112        |
| DTNSRDC<br>Attn: Dr. G. Bosmajian<br>Applied Chemistry Division<br>Annapolis, Maryland 21401                                 | 1                     | Naval Ocean Systems Center<br>Attn: Dr. S. Yamamoto<br>Marine Sciences Division<br>San Diego, California 91232 |
| Dr. William Tolles<br>Superintendent<br>Chemistry Division, Code 6100<br>Naval Research Laboratory<br>Washington, D.C. 20375 | 1                     |  |

**END**

**FILMED**

**12-85**

**DTIC**